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CAVITATION — IS IT ONLY BAD?

by

L. Epshteyn

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ABSTRACT: The principles of cavitation are discussed and its adverse effects cited. The development of cavitation during operation at high rates of speed is unavoidable and all measures to prevent it have been unsuccessful. Cavitation led to the discovery of supercavitation which, in turn, inspired the Russian scientist V. L. Pozdyunin to design supercavitation propellers. The shape of the propeller blades causes rapid development of a cavity that closes behind the propeller, while the simultaneous decrease in resistance and lifting force make it possible to develop a sufficiently high efficiency. Supercavitation conditions set in at speeds of 10 to 100 m/sec or higher. Noise, vibration, and erosion at lower speeds can be eliminated by pumping air in the cavities. Thus, despite its harmful effects, cavitation might eventually find useful application, as have other harmful physical processes in the past. Orig. art. has: 2 figures. English Translation: 10 pages.

CAVITATION — IS IT ONLY BAD?

L. Epshteyn

To become familiar with a problem about which the reader does not have the faintest idea, it is occasionally a good idea to undertake a detailed study of the bibiliography. Here, among the titles of the books and articles it is possible to find everything: the origin of the problem, its development, confusion, prediction, practical significance, and much else.

If we approach the phenomenon of cavitation from this "bibliographic" standpoint, we will note a number of very curious circumstances. It will turn out, first of all, that the word "cavitation" came into being only some 70 years ago. The list of references devoted to this physical phenomenon, however, reveals a work written by Leonard Euler in 1754. This genius of a fluid dynamicist theoretically predicted the possibility of cavitation, although, of course, he was unfamiliar with this term.

For more than a hundred years, cavitation did not give rise to any concern on the part of theoreticians or practitioners in the field. However, during the last 6 years of the 19th Century, the engineers and scientists felt called upon 18 times to express themselves in articles. During the first 20 years of the present century there were 42 articles, with England publishing more articles on cavitation during this period than in all of the other countries combined. During the following 15 years, the number of papers rose well above a hundred and continues to increase.

Behind this dry, formal, graphic change in the number of annual publications there are interesting and frequently dramatic events, precise, expensive experiments and unexpected discoveries. Some of these problems are discussed in the following article.

OUR FIRST ENCOUNTER WITH CAVITATION

The year 1894 may be regarded as the starting point in the experimental study of cavitation. It was that year in which engineers first encountered in practice the phenomenon which had been predicted by Euler some 140 years earlier.

Tests conducted on the British destroyer *Dering* initially suggested no difficulties. The engineers were able to achieve ever increasing

velocity by gradually increasing the rpm's of the propellers. However, at a speed of 24 knots, the further increase in the rpm's did not produce the expected increase in velocity. The engines were on full power, they were turning over at full speed, but... the *Dering* could not achieve 27 knots.

British hydrodynamicists were able to explain the situation correctly. Such low pressures may be developed around the propeller blades at high speeds that a liquid explodes and empty spaces – caverns – are formed within the liquid. Thus the origin of the term *cavitation* – the formation of voids in a liquid.

Cavitation markedly reduces the resistance to the propeller screw, and it was precisely for this reason that the *Dering* was unable to achieve the rated velocity.

Thus it cannot be said that the first encounter with cavitation did not represent a difficult situation for the engineers. The reduction in propeller efficiency was a sufficient source of concern. But the most unpleasant was yet to come.

In 1907, pitting 6-8 cm in depth was noted on the screws of the high-speed liners *Mauritania* and *Lusitania*. The corroded screws which had lost their perfect streamlined shape had to be replaced every two months, at a cost of $70,000 each.

Further unpleasantness was to follow, as if from a horn of plenty. The German navy detected traces of corrosion on the propeller screws of torpedo boats and destroyers within 24 hours of operation and these turned into fist-sized holes within a week. The screws of a hydroplane attempting the establishment of a world record during the forties exhibited as a result of cavitation such a low efficiency that, in order to compensate, a 6400 hp engine had to be mounted on the two-seat vessel. Within 30 years after the first encounter with cavitation, the

chief engineer of the French navy maintained that this phenomenon annually "eats up" millions of horsepower and thousands of tons of fuel.

Hydraulic power engineers soon also were called upon to deal with cavitation. At the Dnepropetrovsk Hydroelectric Power Station, cavitation resulted in shock and turbine vibration. In designing the superpowerful pumps for the Moscow Canal, for the turbines of the Uglich, Rybinsk, Kamsk and other hydroelectric stations, it became necessary to develop measures to protect the rotors against destruction.

COLD BOILING IN A FLOW

We do not need complex equipment in order to produce cavitation.

Everyone is capable of producing, seeing and hearing cavitation. Take a glass tube 10-15 mm in diameter, heat it in the middle in the flame of a gas burner and pull lightly at the ends. A narrow constriction 3-4 mm in diameter will form in the tube. The instrument is now ready. By means of a rubber hose, connect one of the ends of the tube to a water faucet and open the faucet gradually. At first the water will flow quietly out of the tube and the tube will be transparent over its entire length. But then the faucet is opened wider. You will hear a whistling sound and a foggy spot will form in the narrow throat, this spot particularly outstanding against a black background. This spot is the region in which cavitation has taken place. Open the faucet completely and the foggy area will become larger and the noise will increase. If the flow speed and tube dimensions were larger and if the diameter of its minimum cross section were 10-15 mm, the intensity of the noise would be the same as if a thousand-horsepower aircraft engine were turning over only several meters away.

What is taking place in this foggy region?

The greatest speed on the part of the water stream is achieved in the narrowest part of the tube. And at that point in the tube where the

speed is the greatest, the pressure is the lowest; for this reason, by opening the faucet we can reduce the pressure to 0.02 atm. At this pressure the water "boils" at room temperature. This local boiling of a cold liquid is referred to as cavitation. The region occupied by cavitation seems foggy because the light is refracted and reflected from the boundaries of the bubbles [inside the water]. After moving 1-2 cm and again entering a zone of high pressure, the bubbles break up and join together.

The liquid particles in opposite segments collide and produce a noise reminiscent of the clapping of one's hands. These microclaps, merging into a common chorus, produce the sound that is characteristic of cavitation.

In a moving liquid we encounter a change in pressure at each stage.

Skimming past, we see the *Raketa* – a ship on hydrofoils. A rarefaction is produced above the hydrofoil, and a rise in pressure is developed beneath the hydrofoil. The pressure difference across the blades of the propeller screw governs the resistance.The pressure difference between the two sides of the rotor blades sets the rotor in motion. And if the pressure in the region of the rarefaction on the hydrofoil, on the blades of the screw or of the turbine attains the pressure of saturated vapors, we have cavitation and the formation of bubbles.

Whether or not cavitation appears depends on the relationship between the forces compressing or repelling the liquid.

The compressive forces are the larger, the greater the difference between the ambient pressure and the pressure of the saturated vapor in the bubbles.

The repelling forces – centrifugal forces – are produced as the

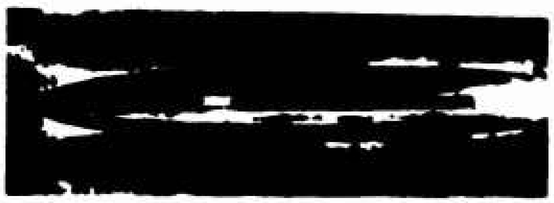
СУПЕРКАВИТАЦИЯ

1) Mechanism of cavitation destruction
2) Profiles of supercavitation screws
3) V. Pozdyunin
4) Tulin
5) Newton-Raider
6) Hydronaut
7) Formation of cacities in supercavitation screw.

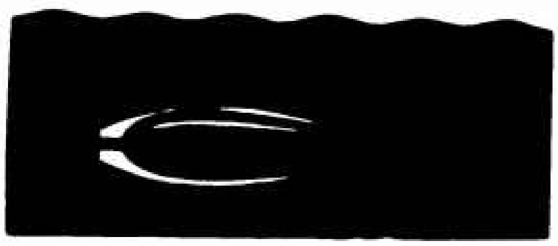
liquid moves along curvilinear trajectories enveloping the obstacle (the foil, the blade). They increase as the velocity, density and curvature of the trajectories increase.

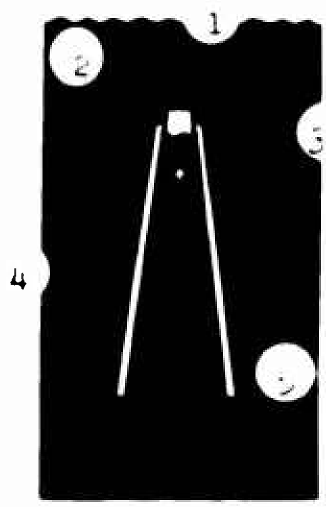
THE DESTRUCTIVE CAVITY

Cavitation is frequently identified with the destruction which it causes. Indeed, erosion owes its existence not to the formation of the



Supercavitation on a rod and on the submarine of the future.





The Parson experiment. 1) Plate; 2) nut; 3) cavity; 4) tube; 5) rubber pad.

cavities, but to their being slammed shut. It turns out that the rate at which the walls of a closing bubble approach each other at moderate flow velocities may reach tens and hundreds of m/sec, while the pressures arising as a result are measured in hundreds and thousands of atmospheres. A thousand strikes in the zone in which the cavities are closing are similar to the effect of a large number of small chisels, removing material from the wall. It has been established that even there where chemical corrosion is impossible, cavitation nevertheless destroys material. Glass, quartz, stainless steel, stellite, gold — nothing can resist cavitation. It is a curious fact that in certain cases vulcanized rubber showed no traces of destruction at points at which even steel was affected. However, if the cavitation intensity exceeds a certain critical magnitude, the rubber begins to peel off and is removed in large pieces. An examination of these pieces showed that the destruction was a result of overheating. It turns out that the kinetic energy of the bubbles slamming shut in the thickness of the rubber layer is converted into heat, and since rubber is a poor conductor of heat, the temperature inside the rubber coating rises above tolerable limits.

In the general case, the process of cavitation destruction is very complex. The mechanical effects are mingled with chemical and electrochemical effects. The air dissolved in the water contains one and a half times as much oxygen as does the atmosphere. This dissolved air is liberated in the region of reduced pressures. The oxidizing processes resulting from the high oxygen content becomes even more pronounced as a result of the fact that the mechanical impacts continuously break up the oxide film which, under ordinary conditions, protects the material and retards the oxidation. A film of this type exhibits reduced mechanical properties, is easily broken up and is carried away by the

flow. A significant role in the intensification of the destruction is played by the fact that the area of the resulting rough surface is considerably greater than the area of a similar smooth surface.

THE "FOES" OF CAVITATION

One of the worst enemies of cavitation is liquid purity. Experiments carried out in 1946 showed that a single cubic centimeter of water from the watermains of the Moscow system contains one part impurities per half million, ranging in size from 1 to 20 microns. A thin layer of undissolved air may be adsorbed on the impurity particle surfaces. Having entered the zone of reduced pressures, such particles easily become the nuclei of bubbles stimulating cavitation. This explains why water subject to purification in porcelain filters or to very great pressure at which all gases enter into solution will not boil at atmospheric pressure even at 200°C. Cavitation does not begin as easily in such water as would be the case in water that has not been purified.

If rivers, seas and oceans could be filtered, and if the surfaces of moving bodies were made wettable, cavitation could be significantly reduced.

However, we must think in terms of more realistic means.

First of all, the rarefaction must be reduced. The lifting force [buoyancy] of the foil, screw, etc., must be distributed over a greater area and profiles that are only slightly distorted and exhibit small angles of attack should be utilized. In certain cases cavitation is eliminated automatically. A great ambient pressure hinders its formation; therefore, in the case of submarines moving at great depths this problem virtually does not arise.

The submarines attain greater depth not for reasons of overcoming cavitation, but in certain cases it is possible and necessary to in-

crease the pressure specifically for this purpose. Thus an increase in the pressure in the fuel tank of a rocket may eliminate pump cavitation.

However, regardless of the measures implemented in order to avoid cavitation, at high speeds it is impossible to eliminate the problem. With an increase in velocity, the white foggy regions on a moving body becomes increasingly larger. Eventually, individual bubbles merge and a pit is formed behind the body - a single cavity filled with vapors of the liquid and therefore completely transparent. Then we have super-cavitation - the flow in which free streams move from the edges of the body. In the case of supercavitation the noise and vibration disappear, but resistance and buoyancy is considerably smaller than in the absence of cavitation. The destruction of the material also ceases: the closure of the cavity takes place in the flow.

This favorable change led the Soviet scientist V.L. Pozdyunin to the concept of supercavitation screws. The blades of such screws are profiled so as to produce cavities that slam shut as quickly as possible behind the screw. The simultaneous reduction in the resistance and buoyancy makes it possible to achieve rather high efficiencies.

Supercavitation regimes are produced at speeds of motion measured in tens and hundreds of meters per second. However, even at smaller velocities it is possible to eliminate the noise, vibration and destruction, by feeding air or some other gas into the rarefaction zone. Generally speaking, the supply of air into a cavitation region is advisable during the initial stage, since its elasticity reduces the impact intensity resulting from the implosions of the bubbles.

The unfavorable effect caused by cavitation have compelled hydrodynamicists for tens of years to seek methods for its suppression or for the elimination of its destructive effects. During this time cavitation acquires a reputation as a harmful phenomenon, although any phy-

sical process, no matter the harm it may have caused the engineer, is capable of useful application. Cavitation is no exception to this rule.

L. Epshteyn
Doctor of Technical Sciences

USEFUL CAVITATION

When certain bodies move in a regime of developed cavitation, they experience less resistance than prior to the appearance of the cavity. This is extremely important for superfast submarines of the future. Even such a negative cavitation effect as the destruction of materials may be utilized for the fragmentation of hard rock, to produce drilling equipment, and for the machining of metals.

It is a curious fact that the first machining of metal by means of cavitation was carried out in 1915 by the Englishman, Parsons, who wanted to demonstrate its destructive effect on propeller screws. To show this, he prepared a massive tube with a brass cover at the narrower end. This tube was immersed into a tank with water and struck against the rubber-padded bottom of the tank. Brought to such a sudden halt, the column of water tore away from the capped end of the tube and a void was instantaneously formed. The water surged back immediately, and this powerful impact went right through the brass plates that were as much as 1 mm thick. It may be that this experiment will lead inventors to new ideas. And it is not out of the question that this will result in "cavitation" machine tools unknown to contemporary practice which will be capable of producing component parts of a variety of materials – metals, plastics, glass...

G. Kotlov
Engineer